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DESIGN OF AN ERROR-BASED ROBUST ADAPTIVE CONTROLLER USING GA BASED PID CONTROLLER

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ABSTRACT

Design of an adaptive controller for complex dynamic systems is a big challenge faced by the researchers. In this paper, we propose a novel method for the design of an error- based robust adaptive controller to make the system response reasonably fast with no overshoot. Here the control action is designed by introducing the notion of 'error-based adaptive controller' (EB-AC) by using GA based PID technique we design feedback controller. This approach for formulating the adaptive controller yields a very fast response with better time response characteristics. In this paper, we present an error-based robust adaptive control design methodology for a linear system and different comparisons are made in MATLAB/ SIMULINK.

KEYWORDS: Adaptive Controller, GA Based PID Technique

INTRODUCTION

Recently there has been an increasing interest from the design of conventional controller to the design of intelligent based control approaches such as adaptive control for controlling a complex dynamic system containing nonlinearity like hysteresis. For decades various schemes of adaptive control have been proposed, and robust adaptive control for nonlinear systems with complex dynamics has received great attention. However, not many of these approaches are suitable for complex nonlinear systems [1-3]. The inverse optimal controller [4-6] using the Lyapunov function is one of the most effective way for designing controllers for nonlinear systems. Using this approach, the controller minimizes a cost function and guarantees the optimality and a stability margin. In this paper, we present a novel design for a robust controller that yields a faster and stable response using the feedback parameters as a function of system error $e(t)$ and its states $x(t)$. In order to illustrate the robustness of this design procedure of the controller, some simulation studies are presented.

DESIGN OF A ROBUST ADAPTIVE CONTROLLER

Step Response for a Second-Order System: Some Important Observations

In our study, we consider a typical open-loop second order plant $G_p(s)$ defined as

$$G_p(s) = \frac{1}{s^2+as+b} \tag{1}$$

As shown in Figure 1, with a feedback controller, the transfer function of the closed-loop system is given by

$$\frac{Y(s)}{R(s)} = \frac{b+K_1}{s^2+(a+K_2)s+b+K_1} \tag{2}$$

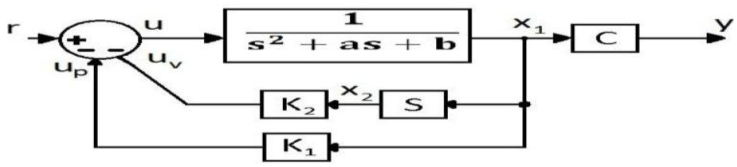

Figure 1: A Typical Second-Order Model and its Closed-Loop System with Two Feedbacks K_1 and K_2

State Vector: $X = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{vmatrix} \frac{1}{c} y \\ \dot{x}_1 \end{vmatrix}$,

Output: $y = Cx_1 = (b + K_1)x_1$

This transfer function can be compared with a general second-order system model as

$$\frac{b+K_1}{s^2+(a+K_2)s+b+K_1} = \frac{\omega_n^2}{s^2+2\varsigma\omega_n s+\omega_n^2} \tag{3}$$

Thus, we see that, $\omega_n^2 = b + K_1 \triangleq K_p$

$$2\varsigma\omega_n = a + K_2 \triangleq K_v \tag{4}$$

Where the parameters K_p and K_v are defined as position feedback and velocity feedback respectively.

Generally the dynamic behavior o0066 a second-order system can be described in terms of two parameters, the natural frequency (ω_n) and the damping ratio (ς). The transient response of a typical control system often exhibits damped oscillations before reaching the steady-state. In specifying the transient response characteristics of a second order control system to a unit-step input, following transient parameters in the design of a controller are usually considered:

Rise time: $T_r = \frac{\Pi-\theta}{\omega_d} = \frac{\Pi-\theta}{\omega_n\sqrt{1-\varsigma^2}}\, \theta = \cos^{-1}(\varsigma)$ (5)

Settling time: $T_s = \frac{4}{\varsigma\omega_n}$ (2% criterion) (6)

Maximum overshoot: $M_p = e^{-\varsigma\Pi\sqrt{1-\varsigma^2}} \times 100(\%)$ (7)

It is important to note that in the step response of the second-order system, the transient values for T_r, T_s and M_p are dependent on the natural frequency (ω_n) and the damping ratio (ς). The positions of the poles of the system are determined by the values of ω_n and ς. In the transient response, it is to be noted that an under damped system (ς <1) yields large overshoot M_p with a larger settling time (T_s), but faster rise time T_r. Whereas, an over damped system (λ >1) yields no overshoot, i.e. $M_p = 0$, but it yields slower T_r and large T_s.

GA BASED PID CONTROLLER

The basic principles of GA were first proposed by Holland. This technique was inspired by the mechanism of natural selection, a biological process in which stronger individual is likely to be the winners in a competing environment. GA uses a direct analogy of such natural evolution to do global optimization in order to solve highly complex problems [7].The GA architecture is shown in Figure 2.

A basic genetic algorithm comprises three genetic operators.

i) Selection ii) crossover iii) mutation

Starting from an initial population of strings (representing possible solutions), the GA uses these operators to calculate successive generations. First, pairs of individuals of the current population are selected to mate with each other to form the offspring, which then form the next generation. Selection is based on the survival-of-the-fittest strategy, but the key idea is to select the better individuals of the population, as in tournament selection, where the participants compete with each other to remain in the population. The most commonly used strategy to select pairs of individuals is the method of roulette-wheel selection, in which every string is assigned a slot in a simulated wheel sized in proportion to the string's relative fitness. This ensures that highly fit strings have a greater probability to be selected to form the next generation through crossover and mutation. After selection of the pairs of parent strings, the crossover operator is applied to each of these pairs. The crossover operator involves the swapping of genetic material (bit-values) between the two parent strings. In single point crossover, a bit position along the two strings is selected at random and the two parent strings exchange their genetic material as illustrated below.

Parent A = a1 a2 a3 a4 | a5 a6

Parent B = b1 b2 b3 b4 | b5 b6

The swapping of genetic material between the two parents on either side of the selected crossover point, represented by "|", produces the following offspring:

Offspring A' = a1 a2 a3 a4 | b5 b6

Offspring B' = b1 b2 b3 b4 | a5 a6

The two individuals (children) resulting from each crossover operation will now be subjected to the mutation operator in the final step to forming the new generation. The mutation operator alters one or more bit values at randomly selected locations in randomly selected strings.

Mutation takes place with certain probability, which, in accordance with its biological equivalent, typically occurs with a very low probability. The mutation operator enhances the ability of the GA to find a near optimal solution to a given problem by maintaining a sufficient level of genetic variety in the population, which is needed to make sure that the entire solution space is used in the search for the best solution. In a sense, it serves as an insurance policy; it helps prevent the loss of genetic material.

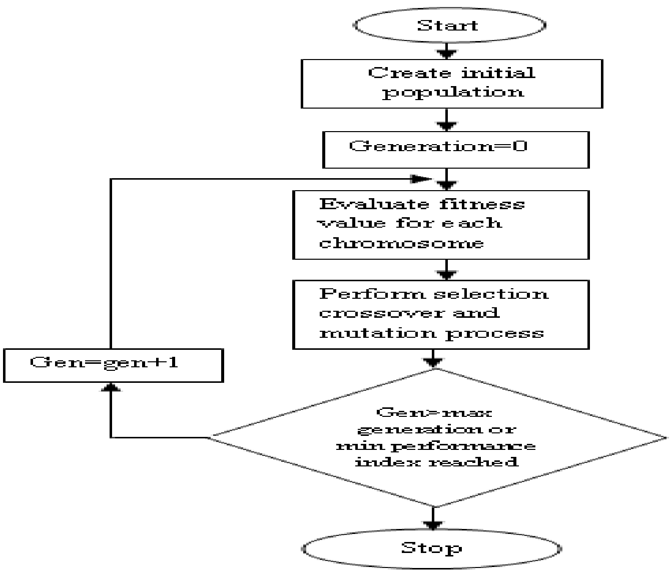

Figure 2: Genetic Algorithm Architecture

SIMULATION RESULTS

The controller transfer function from the GA based PID controller from MS is given by

$$Gc(s) = \frac{7.0168s^2 + 9.7224s + 10.0355}{s}$$

The gains for the PID controller are obtained from Zeigler Nichol method and the following are the results obtained from PID and GA based PID controllers.

MS: The following is the result obtained from MS estimator

MSE: The mean squared error **(MSE)** of an estimator is one of many ways to quantify the difference between values implied by an estimator and the true values of the quantity being estimated.

$$MSE(\hat{\theta}) = E\left[\left(\hat{\theta} - \theta\right)^2\right]$$

ITAE: ITAE integrates the absolute error multiplied by the time over time. What this does is to weight errors which exist after a long time much more heavily than those at the start of the response. ITAE tuning produces systems which settle much more quickly than the other two tuning methods. The downside of this is that ITAE tuning also produces systems with sluggish initial response (necessary to avoid sustained oscillation).

$$ITAE = \int t|E|dt$$

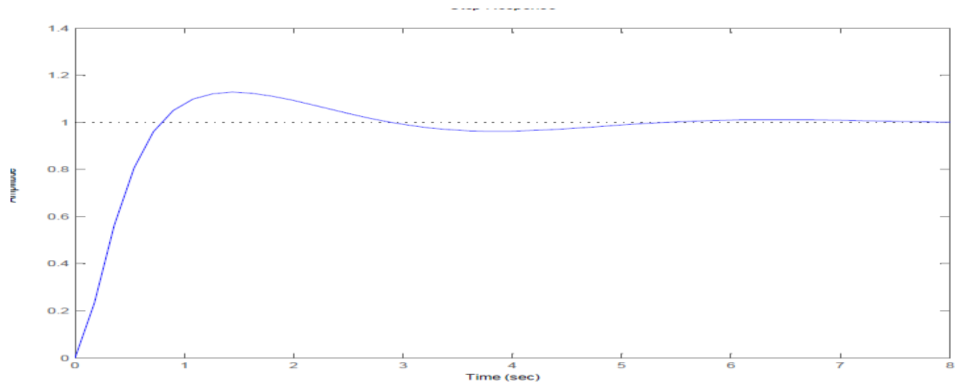

Figure 3: The Transient Response of the Closed Loop System to Unit-Step Input with T_r=0.573sec, Ts=4.74 sec and %Mp =12.7

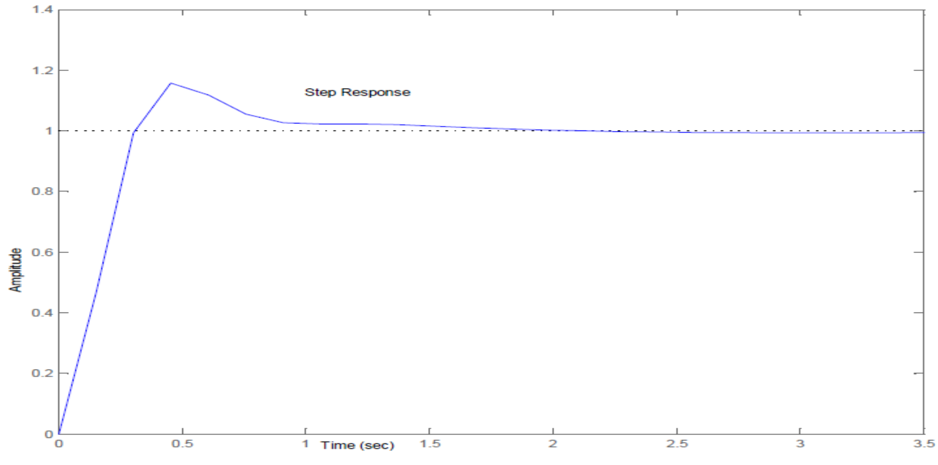

Figure 4: The Transient Response of the Closed Loop System to Unit-Step Input with T_r=0.244sec, T_s =1.36 sec and %M_p =15.76

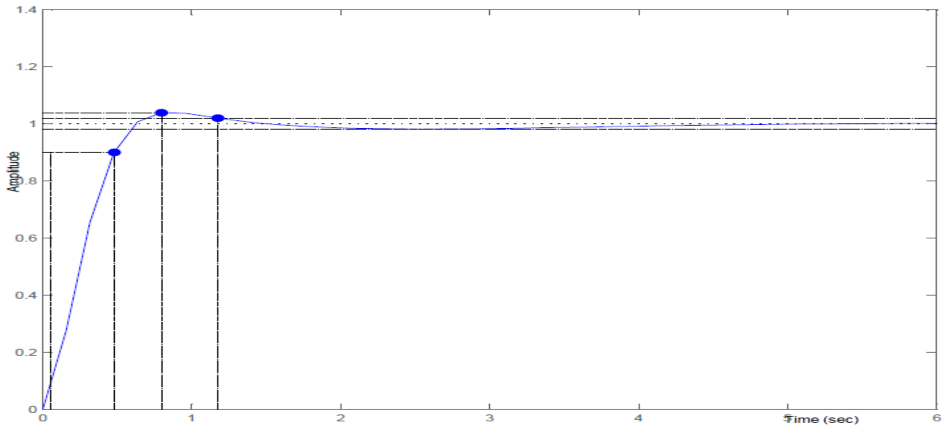

Figure 5: The Transient Response of the Closed Loop System to Unit-Step Input with T_r=0.424sec, T_s =1.18 sec and $\%M_p$ =3.84

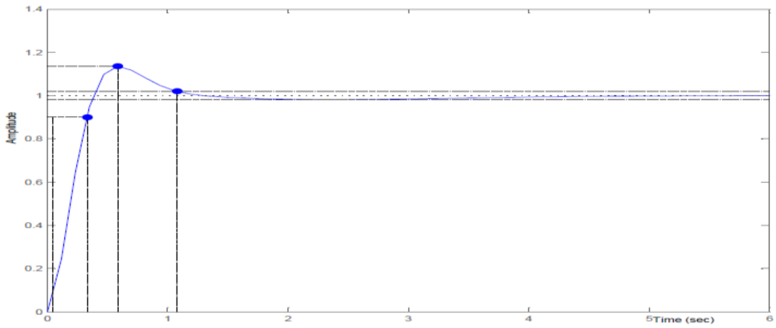

Figure 6: The Transient Response of the Closed Loop System to Unit-Step Input with T_r=0.285sec, T_s =1.08 sec and $\%M_p$ =13.6

The table shows the PID controller gains from PID and GA based PID and time response characteristics from different error mechanisms in GA.

Table 1: Time Response Characteristics of an Error-Based Robust Adaptive Controller

	PID	GA Based PID		
		MS	MSE	IATE
K_P	3.2	9.7224	4.4696	8.3564
K_i	4.3	10.0355	3.5136	5.6729
K_d	2.5	7.0168	3.6429	5.2253
t_r	0.573	0.244	0.424	0.285
t_s	4.74	1.36	1.18	1.08
$\%M_p$	12.7	15.76	3.84	13.6

CONCLUSIONS

In this paper, we have proposed the design of an error-based robust adaptive controller using GA based PID controller for controlling the dynamic response of a system. The design of this robust adaptive controller GA based PID controller is conceptually error-based and can be used to handle the complexity of systems. From the simulation studies, it is shown that the transient response of the closed loop system is very fast yielding with better performance characteristics.

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